STUDIES OF A SCHRAGE THREE-PHASE SHUNT COMMUTATOR MOTOR

I. VECTOR DIAGRAMS AT SYNCHRONOUS AND SUPER-SYNCHRONOUS SPEEDS

By H. P. BHATTACHARYYA AND S. B. DEB

(Received for publication, Feb. 14, 1949)

ABSTRACT. The paper gives the vector diagrams representing all the currents and voltages both on the primary and secondary sides of the Schrage three-phase shunt commutator motor at its synchronous and super-synchronous speeds with a view to obtaining a better understanding of the working of the motor.

INTRODUCTION

The Schrage three-phase shunt commutator motor is a remarkable discovery in electrical engineering practice. It is almost like an ordinary induction motor, having as usual, primary and secondary windings and being rotor-fed the stator winding is the secondary. But unlike the induction motor it has an extra winding called the 'Lap winding' which is electrically insulated from the primary but housed in the same slots as those of the latter. It is, therefore, assumed that there is no leakage of flux between the primary and the lap windings. The lap winding is connected to a commutator on which brushes are placed. For a bi-polar three-phase machine, there are six half-brushes, each pair of which being connected to two ends of each stator secondary phase. This motor can have sub-synchronous, synchronous and super-synchronous speeds, the power factor increasing inherently as it moves faster and faster. Even at sub-synchronous speeds power factor improvement can be brought about by suitably displacing the brush axis from the common stator-rotor axis. Owing to these properties the Schrage motor is widely used in industrial practice now-a-days. One such motor alone, when properly designed, has a wide speed range and thus it is very valuable as a drive where large variation in speeds is required. In point of fact, this variation of speed may be over such a wide range that it will be necessary to use a number of induction and synchronous motors if a Schrage machine is not used.

It is well known that the study of vector diagrams of any A.C. machine is essential for the proper understanding of its operations. Each machine of the ordinary induction or synchronous type has one and only one vector diagram which provides a scientific explanation for its behaviour. But in the case of a Schrage motor, it is felt that its entire operation cannot be fully explained with the help of a single such diagram. For each of the sub-synchronous, synchronous and super-synchronous speed ranges separate vector diagrams are necessary in order to explain the then conditions of the motor. The vector diagram at sub-synchronous speeds of this motor has been worked out by Arnold (1926) but no attempt has yet been made to work out the vector diagrams at the synchronous and super-synchronous speeds. The present paper deals with such vector diagrams.

VECTOR DIAGRAMS

Before describing the vector diagrams it is worthwhile mentioning that voltages are induced in the lap winding due to the primary at the supply frequency, but the voltages collected across any pair of half-brushes are of slip frequency, that is, frequency of the air-gap flux. Below and above synchronism, the slips are positive and negative respectively but at exactly the synchronous speed of the motor the slip is zero. The air-gap flux induces voltages in the stator winding at slip frequencies. These combine with the voltages from the lap winding *via* the brushes. Now since the number of commutator segments between any pair of half-brushes can be varied by rotating the brush-gear thereby varying the voltage injected to the stator, different speeds of the motor are obtained for different injected voltages. It may be noted that the stator induced voltage and the injected voltage from the lap winding are always in opposition. The brush-spread between any pair of half-brushes is generally maximum while the motor is at standstill, and it diminishes as the motor speeds up to a value very close to the synchronous speed when the brushes are short-circuited. Beyond this speed the brushes are crossed over and the voltages are again in opposition, but the current through the stator flows in the same direction as before, thus accounting for the unidirectional rotation of the motor. At sub-synchronous speeds the stator induced voltage dominates over the voltage injected from the lap winding whereas at super-synchronous speeds the case is reverse. At synchronous speed, however, the stator voltage is theoretically equal to zero, although the voltage collected across each pair of half-brushes has a finite value and is unidirectional in nature. At this speed, therefore, there is only a direct current flowing in the lap-secondary combination circuit, which has, however, no influence on the primary side. The diagrams given here are all schematic and refer to symmetrical brush positions of the motor, thus ensuring its inherent tendency for the improvement of the power factor with increasing speed.

The following notations have been used. These refer to per-phase values and it is assumed that the ratio of turns of the rotor primary and the stator secondary is unity.

V = Primary applied voltage

E_1 = Primary induced voltage from the stator

S = Fractional Slip

n = Ratio of effective lap turns for 180 electrical degrees brush displacement to effective stator turns.

α = Ratio of effective lap turns for brush displacement of β electrical degrees to the effective lap turns for brush displacement of 180 electrical degrees, where,

$$\alpha = \operatorname{Sin} \beta/2$$

SE_1 = Stator induced voltage at the slip 'S'.

E_L = Voltage induced in the lap winding between the half-brushes when they are separated by 180 electrical degrees.

E_L/n = Lap induced voltage on the primary.

αE_L = Voltage injected from lap to secondary.

I_1 = Primary current.

I_2 = Secondary stator – lap combination current.

R_1 = Primary Resistance.

X_1 = Primary leakage reactance at supply frequency.

R_2 = Effective stator – lap combination resistance.

X_2 = Effective stator leakage reactance at supply frequency.

Fig. 1 gives the vector diagram at the synchronous speed. According to usual convention the portions above and below the reference axis (the horizontal line to the plane of the paper here) represent respectively the primary and the secondary components of the machine. The stator induced voltage being actually zero in the present case has not been shown. αE_L the lap induced voltage is the only voltage here in the secondary side for producing secondary current I_2. It may be noted that αE_L is just out of phase from E_L/n which is equal to $V - I_1R_1$, where I_1R_1 is the primary resistance drop. Both αE_L and I_2 are unidirectional here. The motor is synchronous in action at this stage and the only difference from an ordinary synchronous motor lies in the fact that it has no salient poles, its rotor is taking the A.C. input power and the stator is taking the D.C. field excitation from the lap winding *via* the brushes. The primary alternating current I_1 shall be considerably larger in magnitude than the secondary direct current I_2 just as in an ordinary synchronous motor.

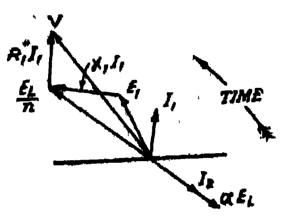

FIG. 1.

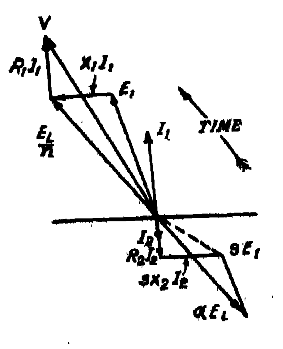

FIG. 2.

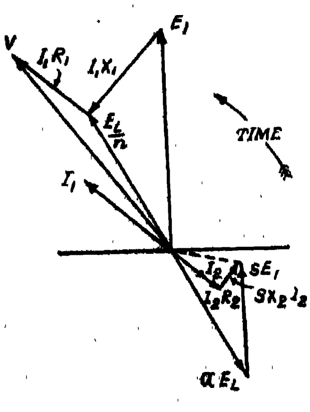

FIG. 3.

Fig. 2 and Fig. 3 represent vector diagrams at super-synchronous speed—power factor lagging and at super-synchronous speed—power factor leading respectively. It may be noted here that though the primary currents are lagging and leading respectively from the supply voltage, the secondary currents in both the cases lag from the respective resultant voltages on this side. In each of the above cases there are two voltages on the secondary side, namely, the lap voltage αE_L and the stator induced voltage SE_1. These two voltages after combining with each other produce a resultant voltage which directs the current I_2 through the secondary circuit. The primary current I_1 is lagging from V in the former case and leading from it in the latter. Accordingly, the primary resistance drop has been subtracted from the supply voltage V in each case to obtain E^L/n the lap voltage induced on the primary. As in Fig. 1, αE_L has been drawn in opposition to E_L/n. The voltage SE_1 though strictly out of phase from E_1, has been taken here in a direction parallel to E_1 in order that it can oppose the voltage αE^L. At any position if the secondary current be I_2 then the primary reflected current I_1 should be given by $I_1 = I_2 (1 + p)$, where $p = \alpha n$.

DISCUSSION

It is worthwhile mentioning here that the principle of drawing of the above vector diagrams is equally applicable when the motor is loaded. The only difference that may arise from the no-load condition is in the degree of the lag of the primary current from the applied voltage, which is definitely less for a loaded motor. A motor at no-load does not ordinarily attain a leading power factor at a super-synchronous speed. Also the possibility of not taking a leading current from the supply is not far from truth even for a motor running at full load and at highest super-synchronous speed. Leading power factor is encountered only in special cases. The primary magnetising current which is small has not been shown separately in the diagrams.

The evaluation of the various performance characteristics of this motor which is likely to throw new light on its performance will be reported in a subsequent communication.

ACKNOWLEDGMENT

Our thanks are due to Prof. P. C. Mahanti, Head of the Department and to Dr. A. K. Sen Gupta, Lecturer-in-Charge of the Electrical Machines Laboratory for their valuable suggestions and encouragement during this work.

ELECTRICAL MACHINES LABORATORY,
DEPARTMENT OF APPLIED PHYSICS,
UNIVERSITY COLLEGE OF SCIENCE & TECHNOLOGY,
CALCUTTA

REFERENCE

Arnold, A. H. M. (1926), *J.I.E.E.*, **64**, 359.